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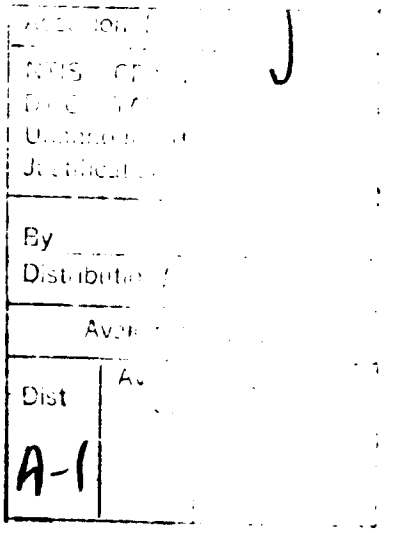

by

David G. Charlton

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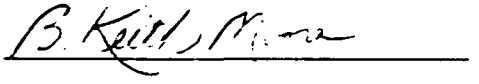

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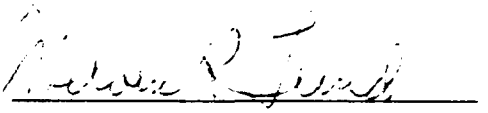

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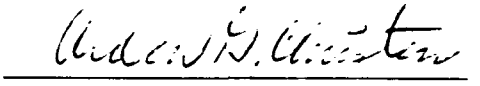

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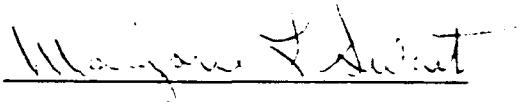

Marjorie L. Swartz

Chairman of the Committee

Date January 31, 1991

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INTRODUCTION

REVIEW OF LITERATURE

Dental amalgam has served as an effective restorative material for over 150 years. Although new restorative systems are continually being developed and employed for the purpose of rebuilding damaged and diseased teeth, amalgam has remained the most commonly used posterior restorative material. In large part, amalgam's constancy has been a result of its many advantages which include ease of manipulation, high strength, and low cost.

As is characteristic of every known material system employed in dentistry, amalgam has certain disadvantages which prevent it from being considered the ideal restorative material. Amalgam allows leakage in the microgap that is always present between it and the cavity margin. While this tendency to leak does decrease over time because of changes which occur in the structure of the material, leakage can lead to undesirable consequences for the patient. Amalgam is also incapable of forming an adhesive bond with tooth structure. This lack of adhesiveness dictates that the dentist provide either undercuts in the tooth or other mechanical means for the retention of the restoration. Both undercuts and retentive devices such as pins and posts can weaken the tooth and often limit the use of amalgam in certain clinical situations.

Although various methods and materials have been employed by dentists in an attempt to overcome the problems of microleakage and lack of adhesiveness, no reliable and consistent way has yet been found to eliminate them.

Recently, however, adhesive resin systems have been used as cavity liners in an attempt to reduce microleakage between amalgam and tooth structure. The resins' ability to adhesively bond amalgam to cavity preparations has also been investigated.

The purpose of this study was to evaluate the efficacy of three commercially available adhesive resin materials in reducing microleakage and providing an adhesive bond between amalgam and tooth structure.

Amalgam has served effectively as a dental restorative material since its introduction to the United States in 1833.[1] Although new dental materials are developed and marketed annually for use in restoring posterior teeth, amalgam is still used in over 75 percent of all direct posterior restorations placed today.[2] This remarkable consistency in the use of amalgam over the last 150 years has, in large measure, been due to its many distinct advantages. Amalgam is noted for its ease of manipulation, long clinical service life, and low cost. Because it is one of the least technique-sensitive direct restorative materials, it accepts a great deal of misuse without failure.[3] Certain amalgam alloys have even been shown to be bactericidal against cariogenic strains of bacteria.[4] As a result of these advantages, and as a testimony to its versatility, amalgam is used not only to restore decayed or damaged posterior teeth, but also to provide a substructure for cast restorations and to seal endodontically treated roots following surgery.[5]

Although amalgam has many advantages which have resulted in its effective use in dentistry, it is not an ideal filling material. As with most other materials, amalgam has its own distinct set of disadvantages. Tarnish and corrosion, mercury allergic reactions, metallic taste, galvanic shock, marginal leakage, nonadhesiveness to tooth structure, and an unesthetic appearance are some of the shortcomings which restrict the use of amalgam in the oral cavity.[6] In particular, microleakage and a lack

of adhesion to tooth structure are shortcomings which have limited the effective use of amalgam in certain clinical situations.

MICROLEAKAGE

Microleakage has been described as the movement of bacteria, fluids, molecules or ions between a cavity wall and the restorative material.[7] The adverse consequences of microleakage at the restoration/tooth interface are well known and include the leaching of constituents from the restorative material,[8] possible secondary (recurrent) caries,[9-11] and staining of the margins due to deposition of corrosion by-products in the microgap between the tooth and filling material.[12] Posttreatment sensitivity may occur as fluid movement takes place between the restoration and the tooth structure. In severe cases this can lead to pulpal inflammation and even necrosis.[13]

Certain characteristics and properties of amalgam have been identified as being important in causing microleakage and influencing the rate with which it occurs. Because amalgam lacks the ability to adhere to tooth structure, a microgap or crevice always exists between the restorative material and the cavity walls.[12] The microgap, which ranges in width from 5 to 20 μm,[14] rapidly fills with dentinal fluid and saliva.[15] Since bacteria are capable of entering crevices of only 2 to 20 μm in width, they are carried into the gap by the saliva. They then form a bacterial film and if the gap's dimensions are only slightly larger, approximately 50 μm, the bacteria gain the capacity to begin the caries forming process.[16,17]

Another property of amalgam which exacerbates the problem of microleakage is its coefficient of thermal expansion.[18] Amalgam expands and contracts from two to three times as much as tooth structure.[19] When significant differences in the coefficient of thermal expansion exist between a restorative material and tooth structure, temperature variations are capable of producing disparate changes in the two materials. Low temperatures produce a negative interfacial pressure which causes inward fluid flow in the microgap. Conversely, high temperatures cause an increase in interfacial pressure and an outward fluid flow. The degree of microleakage has been found to correlate well with coefficients of thermal expansion of restorative materials.[20]

Operator handling characteristics have been shown to influence microleakage, primarily by affecting the intimacy with which the restoration adapts to the cavity margins. Poor adaptation between the amalgam and cavity walls has been shown to contribute to microleakage.[21] Lack of adequate adaptation is commonly seen if a delay occurs between trituration of the amalgam and its condensation or if poor condensation techniques produce voids along critical marginal areas.[12]

The type of amalgam affects the degree of microleakage. Although all newly placed amalgams leak, leakage decreases over time as corrosion occurs and the corrosion by-products fill and seal the microgap separating the amalgam and cavity walls.[22] The rate with which this process proceeds varies for high-copper and low-copper amalgams. Because low-copper amalgams contain more of the corrosion prone tin-mercury phase than do the high-copper amalgams, they leak for a shorter period of time after placement.[23] Differences in particle size and shape also

affect the degree of microleakage.[24] Vasudev et al.[25] monitored the microleakage of amalgams composed of different particle shapes by placing them over a radioactive leucine base material. By measuring the radioactivity of water into which the restored teeth were immersed, they concluded that conventional lathe-cut amalgams more effectively sealed the microgap than did spherical alloys. Other investigators[16,26] have attributed this difference in microleakage to the fact that lathe-cut alloys adapt more intimately to the cavity walls and margins than do spherical alloys.

METHODS OF MEASURING MICROLEAKAGE

A wide variety of techniques have been employed by researchers to study the degree of microleakage between amalgam and tooth structure. The need for different methods stemmed from the realization that the spaces between amalgam restorations and cavity walls are not simply inert and stable microgaps, but "dynamic crevices which contain a busy traffic of ions and molecules."[27] Many studies have employed radioactive isotopes,[28-30] dyes,[31,32] pressurized air,[33,34] calcium hydroxide,[35] bacteria,[36-38] and neutron activation analysis[39] in attempts to study the extent of microleakage.

Use of radioactive isotopes for the study of leakage has been widespread and has several advantages over other methods. Inherently, the isotopes are capable of penetrating more deeply than dyes and autoradiographs are able to detect minute amounts of tracers which would not be visible by other methods.[40]

Radioactive calcium^{45} was one of the earliest and most popular of the tracers used for leakage evaluation. Armstrong and Simon,[41] in one of the first studies using calcium^{45}, evaluated microleakage around several restorative materials placed in class V cavities in extracted human bicuspids. They found that although the isotope Ca^{45} penetrated the margins of all the restorations to varying degrees, amalgam showed the least marginal leakage. Crawford and Larson[42] also used calcium^{45} to measure leakage around different restorative materials. They found that while silicate cement exhibited gross microleakage, amalgam leaked very little and presented only a thin exposure line on the autoradiograph. Phillips et al.[43] used Ca^{45} in the form of calcium chloride to evaluate the degree of microleakage of several restorative materials at varying time periods. Restorations of amalgam, silicate cement, zinc phosphate cement, or acrylic resin were placed in class V cavity preparations in the canines, mandibular second molars, and maxillary bicuspids of dogs. Evaluations were performed 48 hours, 30, 60, and 180 days later. They found that while gross leakage was present at 48 hours in the amalgam restorations, the extent of leakage was reduced at 30 days. No further reduction was seen in the 60 day specimens but a noticeable decrease in the extent of leakage was evident at 180 days.

Other radioactive isotopes have also been employed. Wainwright et al.[44] compared the use of I^{131} and human albumin tagged with radioactive iodine in measuring leakage of class V amalgam restorations. They found definite signs of leakage in all 24 restorations placed and determined that the microleakage appeared less extensive when albumin was used as the tracer. Going et al.[45] also used radioactive iodine in the form of NaI^{131}

to investigate the microleakage of various restorative materials and compared it with the use of crystal violet dye. They found that the amalgam restorations studied showed isotope penetration to less than half the depth of the cervical and incisal margins while penetration of the dye was limited to the marginal walls. Going et al.[46] measured microleakage by using five different radioactive agents. $S^{35}O_4$, $P^{32}O_4$, $Na^{22}Cl$, $Rb^{86}Cl_2$, and $Ca^{45}Cl_2$ were used to determine the degree of leakage of amalgam and nine other restorative materials placed in class V preparations in 147 recently extracted human teeth. The restored teeth were placed for 24 hours in 2 ml of a solution containing one of the five radioisotopes. Autoradiographic evaluation revealed that the isotopes showed varying degrees of microleakage for the amalgam restorations. The S^{35}, Ca^{45}, and the Rb^{86} showed penetration to the pulpal chamber. Na^{22} also penetrated deeply but the extent of penetration seen with the P^{32} was only superficial.

Of the various diffusing materials used to study microleakage, dyes are the most frequently employed.[7] Eosin, methylene blue, methyl violet, hematoxylin and mercuric chloride, Prontosil soluble red, aniline blue, basic fuchsin, crystal violet, and fluorescein have all routinely been used to gauge the extent of microleakage around dental restorations.[40] Parris and Kapsimalis[47] used an aniline blue dye to compare the effects of thermocycling on microleakage around nine restorative materials. They removed the coronal pulp from 117 recently extracted human anterior teeth and inserted cotton into the chamber. After the access openings were filled with one of the nine restorative materials and the roots

sealed to prevent dye from entering the canals, the specimens were either thermocycled or allowed to remain at room temperature. After being immersed in dye for 72 hours, the cotton was examined for signs of dye contamination. Only Cavit and amalgam prevented leakage under both temperature treatment conditions. Mormati and Chan[48] immersed extracted molars restored with either amalgam, direct gold, or acrylic resin in a 0.05 percent crystal violet dye for 24 hours to investigate microleakage. They found that the amalgam and gold restorations exhibited less leakage than the resin restorations.

Pressurized air and other gases have been used to investigate the effects of several variables on the degree of leakage around amalgam restorations. Fanian et al.[49] developed a technique which forced argon gas at 60 psi into the interface between an amalgam restoration and a plastic cavity mold to evaluate the effect of burnishing and cavity varnish on microleakage. It was found that both burnishing and the application of two layers of cavity varnish reduced the amount of leakage detected. In 1988 Hadavi et al.[50] used an air pressure method in an attempt to correlate the degree of porosity in amalgam with leakage at the cavity/restoration interface. Although it was determined that lathe-cut alloys leaked less than other compositional types, no correlation between degree of porosity and leakage was discovered. Fanian et al.[51] investigated the influence of amalgam particle shape on microleakage by forcing pressurized argon gas around amalgam restorations in a plastic mold. Although the technique was found to be capable of quantifying marginal leakage, the researchers recommended against attempting to

anticipate amalgam microleakage based solely on its particle size or composition.

Leinfelder and coworkers[52] have recently introduced a technique using calcium hydroxide for microleakage detection. In the initial study introducing this method, class V preparations were made in the buccal surfaces of molar teeth and calcium hydroxide was placed on the axial walls. After each tooth was restored with either a high-copper or low-copper amalgam alloy, 15 ml of ice-cold water at pH 7 were placed on the alloy surface and allowed to remain undisturbed for one minute. The surface was dried and color indicating pH paper was pressed against the margins of the restoration in an attempt to measure the presence of hydroxyl ions. Testing was performed weekly for 15 weeks. All amalgams showed a reduction in leakage over time and no significant difference was noted between high-copper and low-copper alloys. In 1987 Isenberg and coworkers[53] extended the technique to a clinical setting and used it to evaluate the microleakage of 70 amalgam restorations placed without the use of a cavity varnish. They found that spherical and admixed amalgams exhibited the same decreasing pattern of leakage and concluded that the technique was a viable method for in vivo evaluation of microleakage.

Although these varied methods have been employed successfully by researchers over the years to measure leakage, each has its own disadvantages. The radioisotope method is not particularly well suited for measuring microleakage over an extended period of time.[39] In addition, quantification of isotope penetration is often reduced by chemical affinity of the tracer for the restorative material and autoradiographs are often difficult to interpret because of radiation

diffusion.[54] The detection of microleakage with the use of organic dyes presents difficulties because of the diffusibility of the dye materials[34] and because the toxicity of many dyes precludes their use in in vivo studies.[55] The air pressure technique is often time consuming and, because it requires extensive equipment, is ill-suited for clinical studies.[56] All of these problems to a certain extent limit the effectiveness of these methods for the accurate measurement of marginal leakage.

One technique which uses ultraviolet fluorescing dyes, however, has been used for microleakage measurement and been found to be without many of the problems which characterize other techniques and materials. Proponents of these dyes note that they are extremely bright under ultraviolet light which makes evaluation much easier than with other less obvious markers.[54] Immersion times with these liquids need not be as long as with other agents and the dyes have been shown to be nontoxic and inexpensive.[57] Because they contrast well with the natural fluorescence of dentin and enamel, they photograph well and are easy to detect. Christen and Mitchell,[54] who used the ultraviolet-fluorescing dyes rhodamine B and fluorescein to evaluate microleakage of amalgam, gutta percha, and zinc oxide-eugenol, found that the dyes possessed many of the advantages noted by other researchers. The ability of fluorescent dyes to be extended to the clinical setting for use in measuring intraoral microleakage has made them particularly useful. Loiselle et al.[58] judged a 2 percent fluorescein dye to be effective in evaluating microleakage intraorally and compared the results to an in vitro setting. Their results led them to conclude that leakage should be assessed by in vivo testing

because it more accurately reflects the clinical situation. The many advantages of this type of marker would appear to make it an excellent tool for the investigation of both intraoral and extraoral leakage.

METHODS FOR REDUCING MICROLEAKAGE

A wide range of techniques have been employed in an attempt to reduce the amount of microleakage occurring between cavity walls and amalgam restorations. Most attempts have involved either changes in the way that the amalgam is manipulated, alterations in the design of the cavity preparation, or applications of various types of varnishes to the walls of the preparation.

Burnishing has frequently been proposed as a means of reducing leakage. These recommendations have been based upon studies which indicate that burnishing produces smoother, more homogeneous margins between the amalgam and tooth structure and leads to a better seal.[59-64] Kato et al.[65] used an aerosol dye method to compare microleakage between amalgam and a transparent acrylic cavity in burnished and unburnished specimens. Restorations were either unburnished, burnished immediately after condensation, burnished immediately following carving, or burnished at both times. They found that the unburnished restorations leaked the most while those burnished twice leaked the least. The amalgams burnished either after condensation or after carving fell in between. Russo et al.[66] studied the effects of burnishing and polishing on microleakage using a radioisotope technique. The researchers determined that while polishing had no effect on the degree of microleakage, postcarve burnishing effectively reduced leakage. Other investigators

have found that polishing reduces leakage but that burnishing does so more effectively.[67] Burnishing has also been found to have a beneficial effect in reducing microleakage of high-copper amalgam alloys. Ben-Amar et al.[68] determined that precarve and postcarve burnishing significantly lessened the amount of leakage when used with an admixed high-copper amalgam.

Proper cavity design and careful material manipulation have been mentioned by several authors and researchers as useful ways of reducing microleakage. Certain aspects of cavity preparation, such as rounded internal line angles and smooth walls, promote a better marginal seal and result in less leakage by allowing complete condensation of each amalgam increment.[69] Khera and Chan[70] found that smooth cavity walls produced by hand instrumentation had a significant effect in reducing leakage of amalgam restorations. The condensation technique used by the clinician can also have a significant effect in reducing leakage. Condensation thrusts should be overlapping[71] and adequate force used. Only small increments of amalgam should be condensed[72] and the direction of condensation should be against both lateral and vertical walls.[73]

Varnishes and their effects on microleakage have been extensively investigated.[74-77] Measurements of microleakage using radioisotopes,[78-80] dyes,[81] and in vitro induction of caries[82] have all demonstrated the effectiveness of varnishes in reducing microleakage. Not all varnishes have been shown to be equally effective however. Newman[83] evaluated the effectiveness of four varnishes and compared them to Copalite. Only one of the materials was found to reduce leakage as much as Copalite. Kelsey and Panneton[84] measured the microleakage of

amalgam restorations placed in cavity preparations lined with one of three different varnishes and found that Copalite was the most effective in preventing leakage. Other investigators have also found Copalite to be more efficacious than other resins in sealing the restoration/cavity interface.[85,86] In addition to the type of varnish used, the viscosity of the varnish and its application method are also important in maximizing its sealing ability. Use of a low viscosity varnish[87] as well as application of two separate layers instead of just one have been shown to produce the most consistent results .[88]

Recently, other less conventional materials have been used as cavity liners in an attempt to reduce microleakage of amalgam restorations. Various adhesive resins, in particular, have been studied by researchers who have used them to coat the internal dentin walls and enamel margins of cavity preparations. Their intent has been to reduce leakage by providing a stable, well-sealed interface between the amalgam and tooth structure. Both conventional dentin bonding agents and new adhesive resins which claim the ability to adhesively bond to metal have been evaluated to determine their effectiveness in preventing leakage.

Conventional dentin bonding systems have produced mixed results when used to line amalgam cavity preparations. Yu et al.[89] evaluated six different bonding materials and compared their effectiveness at reducing microleakage to a control restoration which had no cavity liner. Class V preparations were made in extracted human molars and lined with one of the dentin bonding agents prior to being restored with amalgam. After being thermocycled in dye solution, the specimens were sectioned and the degree of dye penetration graded. Differences were noted between the

bonding agents in their ability to prevent microleakage, however all of them reduced leakage more than the control. Keadle et al.[90] compared the effectiveness of Scotchbond 2 with that of Copalite in reducing microleakage of class V amalgam restorations. The enamel margins of one-half of the cavities were etched for 30 seconds with phosphoric acid and then lined with the bonding resin. The other half of the specimens were lined with two separate layers of Copalite. All of the cavities were restored with a single composition spherical amalgam alloy and placed in a basic fuchsin dye after thermocycling. While neither lining material significantly reduced microleakage at the gingival wall margin, the Copalite was determined to have been more effective at limiting occlusal margin leakage. In 1987 Ben-Amar et al.[91] evaluated the microleakage of amalgam restorations placed in cavities lined with Scotchbond. After preparing class V cavities in 44 extracted human molars, they divided the specimens into four groups: those with unlined cavities, those lined with two layers of Copalite, those lined with one layer of Scotchbond, and those lined with two separate layers of Scotchbond. The enamel margins of the resin-lined preparations were also etched with 35 percent phosphoric acid for 30 seconds prior to the application of the resin. Following thermocycling for 200 cycles in a 0.5 percent basic fuchsin dye, the teeth were longitudinally sectioned and examined for dye penetration. Use of two layers of Scotchbond totally eliminated leakage at the occlusal margins, and no significant difference was found between the Scotchbond and Copalite groups. At the gingival margins, however, the Scotchbond specimens exhibited significantly less leakage than did the Copalite groups.

While studies of the conventional bonding resins have produced indications that they may be efficacious in reducing amalgam microleakage, more recently developed adhesive systems have superseded them as subjects in this line of research. In particular, resins based on the bisphenyl-A glycidyl methacrylate (BIS-GMA) monomer or the methacryloxyethyl trimellitic anhydride (4-META) monomer have been studied in some depth.

Simizu et al.[92] evaluated the effectiveness of a BIS-GMA based resin adhesive, Panavia, with and without a glass ionomer cement liner and a fluoride treatment in reducing microleakage of amalgam. Twenty-four extracted molars were divided into six groups which received various treatment combinations of a glass ionomer liner, fluoride wash, and Panavia. A 1 percent methylene blue dye technique revealed that the Panavia-lined cavities showed less leakage than did the unlined controls. An even greater reduction in leakage was exhibited by the cavities lined with the glass ionomer cement and Panavia. The authors concluded that Panavia was effective in reducing microleakage when used as a liner with amalgam. Torii et al.[93] used a caries inhibition method to study microleakage between amalgam and cavity walls lined with Panavia. They found that caries penetration along the cavity walls of the lined preparations was significantly reduced compared to unlined cavities. Staninec and Holt[94] compared the extent of microleakage in class V amalgam restorations where the cavity walls were lined with either two layers of Copalite or Panavia. The Panavia was placed after etching the enamel margins of the preparations with 37 percent phosphoric acid for

30 seconds. A dye penetration technique revealed that in every specimen, the resin-lined cavities leaked less than the varnish-lined preparations.

BIS-GMA and 4-META resins have also been compared with each other to gauge their relative effectiveness in reducing leakage in amalgam restorations. Varga et al.[95] prepared class I cavities in extracted molars and premolars and applied to each one of the following treatments: 4-META or Panavia EX following etching, 4-META or Panavia EX without etching, or no treatment. After being restored, the specimens were placed in a basic fuchsin dye for 24 hours. The restorations were then polished and the teeth placed in the dye for one week. Evaluation of dye penetration revealed that all of the non-etched, non-lined specimens showed leakage while only one of the non-etched, resin-lined cavities showed leakage. No signs of dye penetration were visible for any of the etched, resin-lined restorations. The Panavia EX and the 4-META resins were found to be equally effective in reducing leakage.

LACK OF ADHESION

Unlike other currently available restorative materials, amalgam is unable to chemically bond to tooth structure.[96] This inability to bond to enamel and dentin is a distinct disadvantage and presents the clinician with several problems when amalgam is used for the restoration of decayed or fractured teeth.

Since amalgam does not adhesively bond to the cavity walls of a preparation, a microspace or gap always separates the two and provides a ready avenue for fluid, bacteria, and debris. Resulting microleakage can

lead to posttreatment sensitivity, recurrent caries, pulpal inflammation, and necrosis.

A lack of adhesion between amalgam and tooth structure means that restorations are held in place only by the retention form provided by the clinician.[97] Often, retentive undercuts or pins placed in the remaining tooth structure compromise the restoration or seriously damage the tooth. Undercuts in the walls or floors of the cavity preparation frequently require the removal of healthy enamel or dentin which can cause serious problems by weakening the remaining tooth structure and leading to fracture of the tooth and failure of the restoration. Because retentive pins conserve more tooth structure than grooves or slots, they do not weaken the remaining enamel and dentin to the extent that the other retentive methods do. The use of pins does, however, have other adverse effects on the tooth and restoration. Although at one time pins were believed to strengthen and reinforce amalgam, it is now clear that they significantly reduce the amalgam's transverse and tensile strengths and, to a lesser degree, reduce its compressive strength.[98,99] Drilling pinholes and placing threaded pins creates craze lines and generates stress in the dentin.[100,101] These lines may weaken the tooth and make it more susceptible to fracture. Craze lines not only weaken the tooth but have also been shown to extend into the pulp chamber.[102] Leakage which commonly occurs around all types of pins may contaminate the pulp by traveling down these cracks and cause pulpal inflammation. Pin placement also brings with it the possibility of pulpal exposure or perforation of the external surface of the tooth.[103] These problems often require correction with separate surgical or endodontic treatment.

In an attempt to eliminate the problems associated with mechanical forms of retention, investigators have studied the use of resin liners to provide an adhesive bond between amalgam and cavity preparations. As was the case for studies evaluating resins for reducing microleakage, the majority of these studies have focused on the BIS-GMA based resins, Panavia or Panavia EX, and various resin liners consisting of the 4-META monomer.

Staninec[104] studied the effects of an adhesive resin liner and mechanical undercuts on the retention of amalgam in proximal cavity preparations placed in extracted human teeth. He divided 52 teeth into four groups and prepared each specimen with a boxform proximal cavity having parallel walls. The preparations for each group were then varied. The first group of 13 was left unmodified. The second group received a glass ionomer liner and the adhesive resin, Panavia. Proximal retentive grooves were added to each specimen in group three, while the specimens in the remaining group were modified with an occlusal dovetail. All of the preparations were then restored with amalgam. Following a suitable waiting period, the mean force required to dislodge the restorations was measured. The group in which the preparations were lined with the adhesive resin had a significantly higher bond strength than the others.

In 1986 Shimizu et al.[105] investigated the bond strength of amalgam to bovine enamel and dentin treated with different combinations of fluoride, glass ionomer cement liners, and adhesive resins. The specific adhesive systems studied were Panavia and the 4-META resin, Super-Bond. Amalgam was found to adhere to both enamel and dentin when treated with the resin agents. The highest bond strengths measured were between

Panavia-treated enamel and amalgam and between Super-Bond-treated enamel and amalgam. These results led the authors to suggest that the use of these adhesives as amalgam liners be extended to the clinical setting.

The potential for adhesive resins used as amalgam liners to increase fracture strength of teeth was investigated by Eakle et al.[106] They prepared 14 extracted human premolars with MOD cavities using an isthmus width of one-third of the buccolingual intercuspal dimension. One-half of the specimens were restored with a spherical high-copper amalgam. The enamel margins of the other specimens were etched with a 37 percent phosphoric acid for 30 seconds. Panavia EX was applied to both the etched enamel and the unetched dentin walls and the specimens were restored with amalgam. Following a storage period of 24 hours, the teeth were thermocycled for 240 cycles and an Instron testing machine was used to measure fracture strengths by loading cuspal inclines to the point of fracture. Testing revealed that the fracture strength of the bonded specimens was significantly higher than the unbonded ones. The authors recommended that clinical testing be undertaken to determine the effectiveness of using adhesive resins as lining materials under amalgam.

In 1989 Cooley et al.[107] evaluated the effect that amalgam surface finish had on bond strength to two resin adhesives, Cover-Up II, a 4-META adhesive, and Panavia. The amalgam surfaces to be bonded were finished with either a diamond bur or an air polisher prior to application of the resin liner. The researchers found that the amalgam surfaces treated with a diamond bur had higher bond strengths than those finished with the air polisher. Significant differences were also noted between resin

systems, with Cover-Up II producing a stronger bond to amalgam than Panavia.

METHODS AND MATERIALS

RETENTION TEST

Preparation of Specimens

A total of 100 extracted, intact human molars were used for the retention test. The crowns were sectioned from their roots at the level of the cementoenamel junction using a sectioning machine (Thin Sectioning Machine, Hamco Machines, Inc., Rochester, NY) with a diamond disk and under a constant stream of water. The crowns were mounted in the center of autopolymerizing acrylic resin cylinders to expose a flat buccal, lingual, or proximal enamel surface. Each specimen was mounted in the chuck of a 3 inch lathe (Sears Craftsman Model 527-2142, Sears, Chicago, IL) (Figure 1) and a cavity 3.5 mm deep and 3 mm in diameter was prepared using a 557 carbide bur in a high speed handpiece with water spray coolant. Each bur was used to prepare only 15 cavities. The angle between the pulpal floor and the lateral walls was 2 degrees. Just prior to the treatment of each cavity preparation, the preparation was cleansed with 3 percent hydrogen peroxide for 10 seconds, rinsed and dried. Five test groups, each consisting of 20 specimens, were prepared to test three commercially available adhesive resin systems (Table I):

Group 1 No varnish or liner; restored with Tytin.

Group 2 Copalite varnish; restored with Tytin.

Group 3 Prisma Universal Bond 2; restored with Tytin.

Group 4 Panavia EX; restored with Tytin.

Group 5 Amalgambond; restored with Tytin.

Detailed preparation procedures for the five groups follow:

Group 1 A 3/4 inch by 18 gauge flat-headed wire nail was placed into the cavity with the head resting on the pulpal floor. The diameters of both the nail head and the pulpal floor were 3 mm which ensured that the nail head completely covered the pulpal floor. Tytin (Sybron/Kerr, Romulus, MI) was triturated for five seconds at the M2 setting of a triturator (Vari-Mix II, L.D. Caulk/Dentsply, Milford, DE) and immediately condensed into the preparation using a small diameter condenser (2T, GC American Dental, Scottsdale, AZ). Carving of the restoration was begun when the amalgam first provided resistance to the carving instrument. An interproximal instrument (IPC, GC American Dental) was used to carve the restoration flush to the external surface of the tooth (Figure 2).

Group 2 Two separate layers of Copalite (Harry J. Bosworth Co., Skokie, IL) were applied to the internal walls of the preparation. The first layer was air dried for five seconds prior to the application of the second layer. A 3/4 inch by 18 gauge flat-headed wire nail was placed into the cavity with the head resting on the pulpal floor. Tytin was triturated and condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described.

Group 3 Caulk Tooth Conditioner (Caulk/Dentsply) was applied to the enamel margins with a small brush and allowed to remain in place for 60 seconds. The etched surface was then rinsed with a stream of water for 20 seconds and dried with compressed air for 20 seconds. Prisma Dentin

Primer was applied with a fine brush to the dentin cavity walls and left undisturbed for 30 seconds. The cavity was dried for 10 seconds. Prisma Adhesive was then applied to the primed dentin and etched enamel walls with a brush. A gentle stream of compressed air was directed into the preparation to produce a thin and uniform layer of adhesive. Excessive thinning of the adhesive was avoided. The adhesive was polymerized with a 10 second exposure to a visible light unit (COE-Lite, Imperial Chemical Industries PLC, Macclesfield, England). A thin layer of Copalite was applied to the bottom of the head of a 3/4 inch by 18 gauge flat-headed wire nail to prevent the nail from adhering to the resin adhesive. The nail was placed in the preparation so that its head was resting on the pulpal floor. Tytin was triturated and condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described.

Group 4 The enamel margins were etched for 30 seconds with 37 percent phosphoric acid, rinsed for 40 seconds and dried for 20 seconds. One coat of Panavia EX was applied with a brush to the dentin walls of the preparation and to the etched enamel margins. A 3/4 inch by 18 gauge flat-headed wire nail with a thin layer of Copalite on the bottom surface of its head was placed into the cavity with the head resting on the pulpal floor. Tytin was triturated and condensed into the preparation and the restoration was carved flush tc the external surface of the tooth as previously described. Immediately following completion of carving, Oxyguard was applied to the margins of the restoration with a brush.

Group 5 Amalgambond Activator was applied to the dentin cavity walls with a fine brush and left undisturbed for 10 seconds. The

Activator was then applied to the enamel margins and left undisturbed for 30 seconds. The cavity was rinsed with a stream of water for 20 seconds and dried with compressed air for 20 seconds. Amalgambond Adhesive was applied with a brush to the dentin surfaces and left undisturbed for 30 seconds. A gentle stream of compressed air was directed into the preparation to produce a thin and uniform layer of the adhesive. Amalgambond Base and Catalyst were mixed according to the manufacturer's instructions and applied to the dentin walls and enamel margins of the cavity. In accordance with the manufacturer's recommendation, the base and catalyst mixture was not allowed to dry prior to the restoration of the cavity. A 3/4 inch by 18 gauge flat-headed wire nail with a thin layer of Copalite on the bottom surface of its head was placed into the cavity with the head resting on the pulpal floor. Tytin was triturated and condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described.

Following preparation, the specimens were stored for 24 hours in distilled water at 37°C.

Thermocycling

Using a thermocycler (Figure 3), each group was subjected to 2,500 thermocycles between two water baths having a 40°C temperature differential. A 5°C bath and a 45°C bath were used with a 30 second dwell time and a transfer time of 10 seconds. After thermocycling, the specimens were stored in distilled water at 37°C.

Retention Test

Retention testing was performed five days after specimen preparation. A threaded steel jig and wire basket (Figure 4) were used for the test. Each specimen was attached to an Instron Universal Testing Machine (Instron Corporation, Canton, MA) by suspending the acrylic resin base of the specimen from the wire basket and inserting it into the upper grip. The exposed nail projecting from the specimen was fastened into the threaded steel jig and inserted into the lower grip (Figure 5). The specimens were loaded to failure in tension at a crosshead speed of 2 mm/min and the load required for failure was recorded on a strip chart. The mode of failure was grossly observed and recorded as adhesive, cohesive, or mixed. Adhesive failures were those in which the nail and amalgam were removed from the preparation intact without leaving amalgam in the preparation or causing fracture of the tooth structure. Although it is possible in this type of separation that the actual location of the failure was cohesive within the adhesive resin, difficulty in detection required that both amalgam/adhesive and adhesive/tooth structure interface failures be recorded as being adhesive. Cohesive failures were those which failed entirely within the tooth structure and mixed failures failed within both tooth structure and between the amalgam and tooth structure.

Statistical Analysis

A Hartley test performed on the data indicated homogeneity of the group variances. The data were analyzed by one-way analysis of variance to determine if significant differences existed between the five

treatment groups. Because significant differences were found, multiple comparisons were made between group means by employing Fisher's Least Significant Differences method.

MICROLEAKAGE TEST

Preparation of Specimens

A total of 100 extracted, intact human cuspids and bicuspids were used for the microleakage test. In each of the teeth a 3 mm mesiodistal by 2 mm occlusogingival by 2 mm deep class V cavity was prepared in the middle third of the facial surface using a 557 carbide bur in a high speed handpiece with water spray coolant. Each bur was used to prepare only 15 cavities. Preparation outline form was ovoid and cavosurface margins were butt joint and entirely within enamel. All preparations were made in as uniform a manner as possible with regard to instrumentation, form, and dimension. Just prior to the treatment of each cavity preparation, the preparation was cleansed with 3 percent hydrogen peroxide for 10 seconds, rinsed and dried. Five test groups, each consisting of 20 specimens, were prepared to test the following variables:

Group 1 No varnish or liner; restored with Tytin.

Group 2 Copalite varnish; restored with Tytin.

Group 3 Prisma Universal Bond 2; restored with Tytin.

Group 4 Panavia EX; restored with Tytin.

Group 5 Amalgambond; restored with Tytin.

Detailed preparation procedures for the five groups follow:

Group 1 Tytin (Sybron/Kerr, Romulus, MI) was triturated for five seconds at the M2 setting of a triturator (Vari-Mix II, L.D. Caulk/Dentsply, Milford, DE) and immediately condensed into the preparation using a standard amalgam condenser (3T, GC American Dental, Scottsdale, AZ). Carving of the restoration was begun when the amalgam first provided resistance to the carving instrument. An interproximal instrument (IPC, GC American Dental) was used to carve the restoration flush to the external surface of the tooth.

Group 2 Two separate layers of Copalite were applied to the cavity walls. The first layer was air dried for five seconds prior to the application of the second layer. Tytin was triturated and condensed into the cavity and the restoration was carved flush to the external surface of the tooth as previously described.

Group 3 Caulk Tooth Conditioner was applied to the enamel margins with a small brush and allowed to remain in place for 60 seconds. The etched surface was rinsed with a stream of water for 20 seconds and dried with compressed air for 20 seconds. Prisma Dentin Primer was applied with a fine brush to the dentin cavity walls and left undisturbed for 30 seconds. The cavity was dried for 10 seconds and Prisma Adhesive was then applied to the primed dentin and etched enamel walls with a brush. A gentle stream of compressed air was directed into the preparation to produce a thin and uniform layer of adhesive. Excessive thinning of the adhesive was avoided. The adhesive was polymerized with a 10 second exposure to a visible light unit. Tytin was triturated and

condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described.

Group 4 The enamel margins were etched for 30 seconds with 37 percent phosphoric acid, rinsed for 40 seconds and dried for 20 seconds. One coat of Panavia EX was applied with a brush to the dentin walls of the preparation and to the etched enamel margins. Tytin was triturated and condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described. Immediately following completion of carving, Oxyguard was applied to the margins of the restoration with a brush.

Group 5 Amalgambond Activator was applied to the dentin cavity walls with a fine brush and left undisturbed for 10 seconds. The Activator was then applied to the enamel margins and left undisturbed for 30 seconds. The cavity was rinsed with a stream of water for 20 seconds and dried with compressed air for 20 seconds. Amalgambond Adhesive was applied with a brush to the dentin surfaces and left undisturbed for 30 seconds. A gentle stream of compressed air was directed into the preparation to produce a thin and uniform layer of the adhesive. Amalgambond Base and Catalyst were mixed according to the manufacturer's instructions and applied to the dentin walls and enamel margins of the cavity. In accordance with the manufacturer's recommendation, the base and catalyst mixture was not allowed to dry prior to the restoration of the cavity. Tytin was triturated and condensed into the preparation and the restoration was carved flush to the external surface of the tooth as previously described.

Following preparation, the specimens were stored for 24 hours in distilled water at 37°C.

Thermocycling

Using a thermocycler, each group was subjected to 2,500 thermocycles between two water baths having a 40°C temperature differential. A 5°C bath and a 45°C bath were used with a 30 second dwell time and a transfer time of 10 seconds. After thermocycling, the specimens were stored in distilled water at 37°C.

Microleakage Test

Microleakage testing was performed five days after specimen preparation. The apices of the teeth were sealed with impression compound and the teeth were coated to within 1 mm of the cavity margins with nail polish. While still tacky, tin foil was adapted over the teeth and up to 1 mm from the cavity margins. Nail polish was then applied to the seams of the tin foil to ensure complete sealing (Figure 6). The specimens were immersed for 24 hours in a 2 percent aqueous solution of a fluorescent dye (Zyglo Penetrant ZL-54, MagnaFlux Corp., Chicago, IL) and stored at 37°C. Each tooth was sectioned buccolingually using a sectioning machine to produce a longitudinal section through the restoration (Figure 7). The facial surface of the restoration was coated with a dark nail polish to reduce scattered illumination from dye exposure to the exposed marginal area. A code number was written on the root surface of the tooth and the specimen was mounted flat on a piece of

paper stock using brown impression compound to allow the examiners to view the cavity margins from the same angle.

Evaluation

The specimens were illuminated by two ultraviolet light lamps (Blak-Ray, Ultra-Violet Products, Inc., San Gabriel, CA). Aluminum cones were positioned over the lamps to direct the light toward the specimens and to eliminated scatter illumination (Figure 8). Two independent evaluators examined the cavities with the aid of a stereomicroscope at X25 magnification and scored the degree of microleakage according to a predetermined standard as shown in Figure 9. The diagram corresponds to the following degrees of dye penetration:

1 = No penetration.

2 = Penetration up to one-half of the distance from the margin to the axial wall.

3 = Penetration from the margin to the axial wall.

4 = Penetration along the axial wall.

Two measurements were made for each specimen; one for the occlusal wall margin and one for the gingival wall margin. The examiners evaluated the specimens three times with at least a 24 hour time lapse between evaluations.

Statistical Analysis

The three sets of microleakage scores obtained by the two evaluators for the occlusal and gingival margins of each specimen were compiled and the Pearson correlation method was employed to evaluate for interevaluator and intraevaluator agreement. Because no significant difference was found for the interevaluator and intraevaluator evaluations, the majority score for each of the two margins of each specimen was used. Ridit analysis was performed to obtain ridit means and standard deviations for the occlusal and gingival margins for each of the five groups. Variances for the occlusal and gingival margins within each group were determined to be homogeneous by Bartlett's test and one-way analysis of variance at the 0.05 probability level indicated that no significant differences existed between the two margins for each treatment group. As a consequence, the occlusal and gingival scores within each treatment group were combined to produce a sample size of 40 and new ridit means and standard deviations were calculated. Since Bartlett's test found these new variances to be non-homogeneous, Welch's test was performed to determine if significant differences existed between the groups at the 0.05 probability level. Significant differences were found and multiple comparisons were carried out using the Newman-Keul's test.

RESULTS

RETENTION TEST

Comparisons of the Five Treatment Groups

The mean loads at failure for the five treatment groups are presented in Table II and Figure 10. The Analysis of Variance test indicated a significant difference between the groups at the 0.05 probability level. Multiple comparisons performed using Fisher's Least Significant Differences method revealed that the Panavia EX and Amalgambond groups exhibited significantly higher mean loads at failure than did the other three groups. Furthermore, the Prisma Universal Bond 2 group had a significantly higher mean failure load than did the Copalite group and the group which received no treatment.

The Panavia EX and Amalgambond had the highest mean loads at failure (37 kg) followed by Prisma Universal Bond 2 (31 kg), and the group receiving no treatment (26 kg). The Copalite group had the lowest mean load at failure (22 kg).

Failure Mode of the Five Treatment Groups

The distribution of failure modes for the treatment groups is presented in Table III. The group which received no treatment exhibited an adhesive failure rate of 100%. The modes of failure for the Copalite group were 85% adhesive and 15% mixed. The Prisma Universal Bond 2 group showed 70% adhesive and 30% mixed failure rates while the Panavia EX

group exhibited almost the reverse situation with a 35% adhesive rate of failure and a 65% mixed rate. The Amalgambond group experienced 70% adhesive and 30% mixed failure rates. In no instance did an entirely cohesive failure within tooth structure occur during testing.

MICROLEAKAGE TEST

The distribution and degree of microleakage for the occlusal and gingival margins of each treatment group are presented in Table IV.

Ridit means and standard deviations for the five treatment groups are presented in Table V. Larger ridit means indicate a greater degree of leakage than smaller means.

Comparisons of the Five Treatment Groups

The mean ridit values and standard deviations for the five treatment groups are shown in Table V and Figure 11. Ridit means ranged from 0.30 for the Amalgambond group to 0.62 for the Copalite group. The Amalgambond group was significantly different from the other groups. There were 22 leakage scores in Category 1 and 17 in Category 2. The Copalite, Prisma Universal Bond 2, and Panavia EX groups exhibited more leakage than did the Control (No Treatment) group, but the differences were not statistically significant. The Control group had a large standard deviation with 21 leakage scores in Category 1 and 19 in Category 4 while the three remaining groups, the Copalite, Prisma Universal Bond, and Panavia EX, had the majority of their leakage scores in Category 2.

RELATIONSHIP BETWEEN RETENTION TEST AND MICROLEAKAGE

The rank orders of the mean loads at failure and microleakage for the five groups are shown in Table VI. Although an exact correlation between the results was not found, the Amalgambond group ranked first in both tests while the Copalite group ranked last.

FIGURES AND TABLES

FIGURE 1. The lathe used for the preparation of specimens for the bond tests.

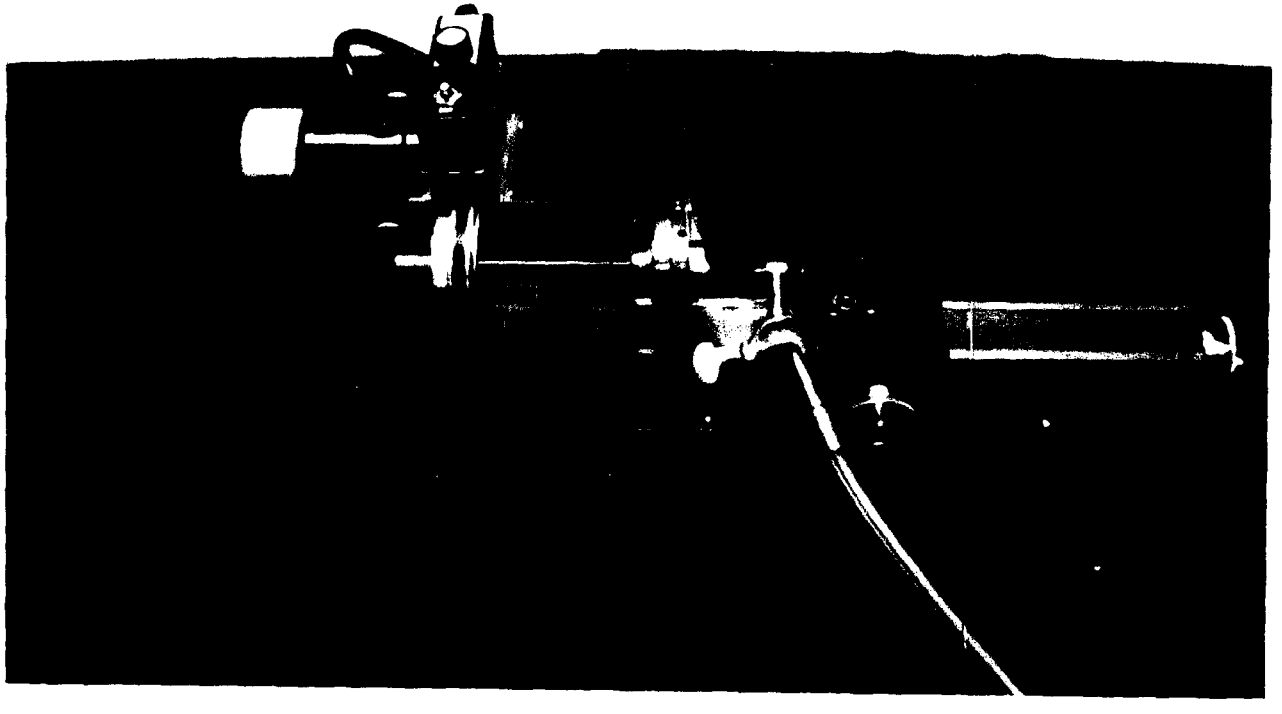


FIGURE 2. A specimen prepared for bond testing. The head of the wire nail rests on the pulpal floor of the preparation.

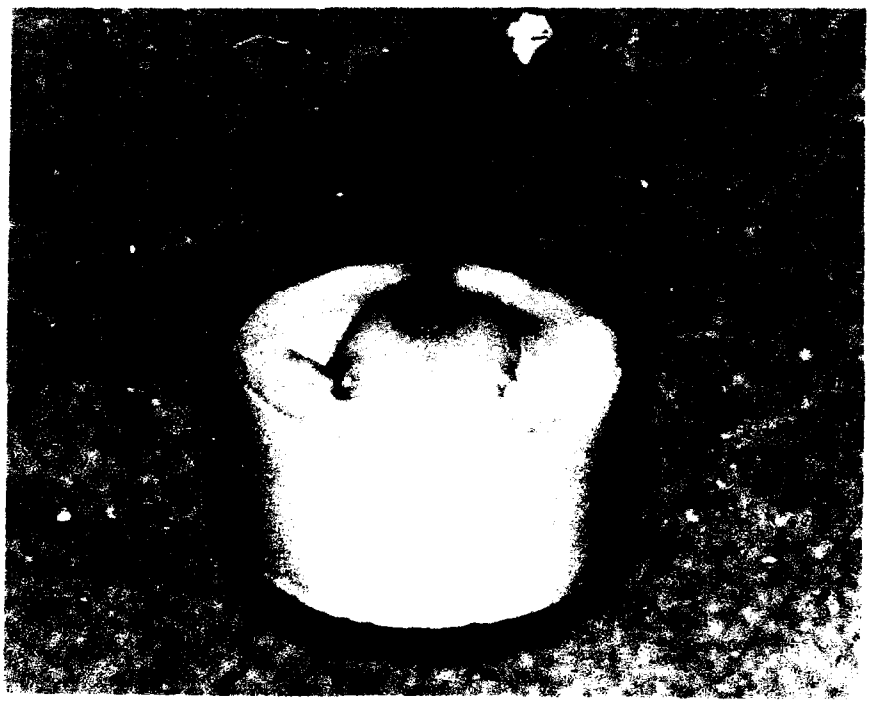


FIGURE 3. The thermocycler used to thermal stress the bond and microleakage specimens.

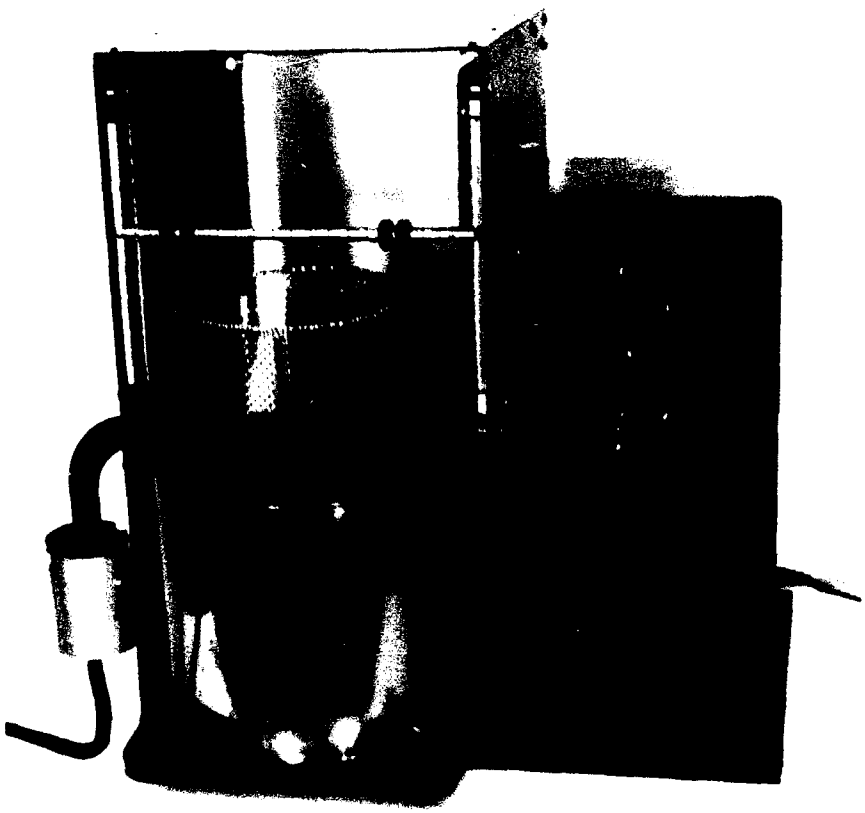


FIGURE 4. Testing jigs used for the bond testing. The wire basket was used to hold the acrylic resin base into which the specimen was mounted and the threaded jig was used to engage the wire nail projecting from the amalgam restoration.

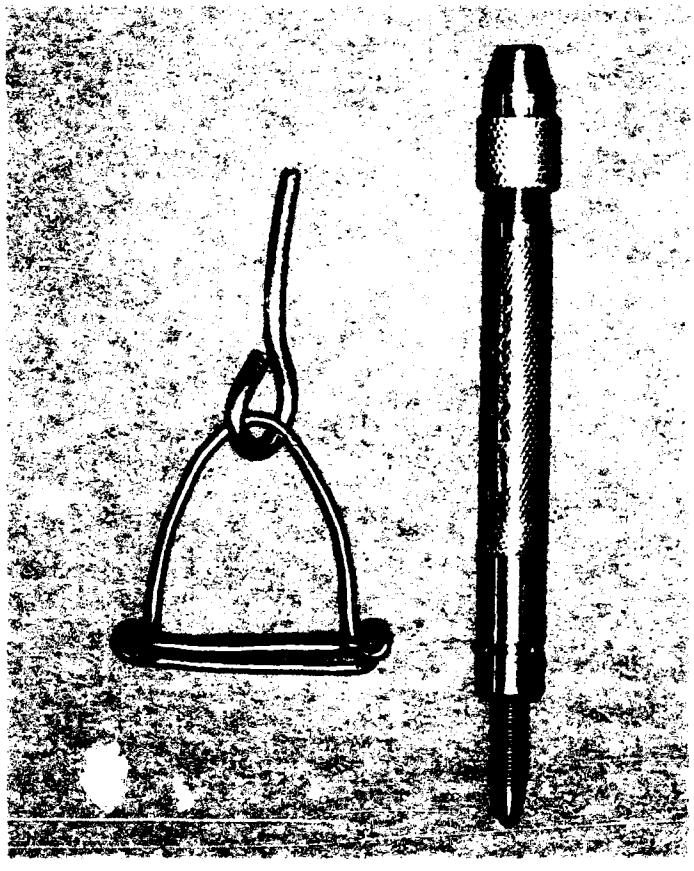


FIGURE 5. The apparatus for bond testing mounted in the Instron machine.

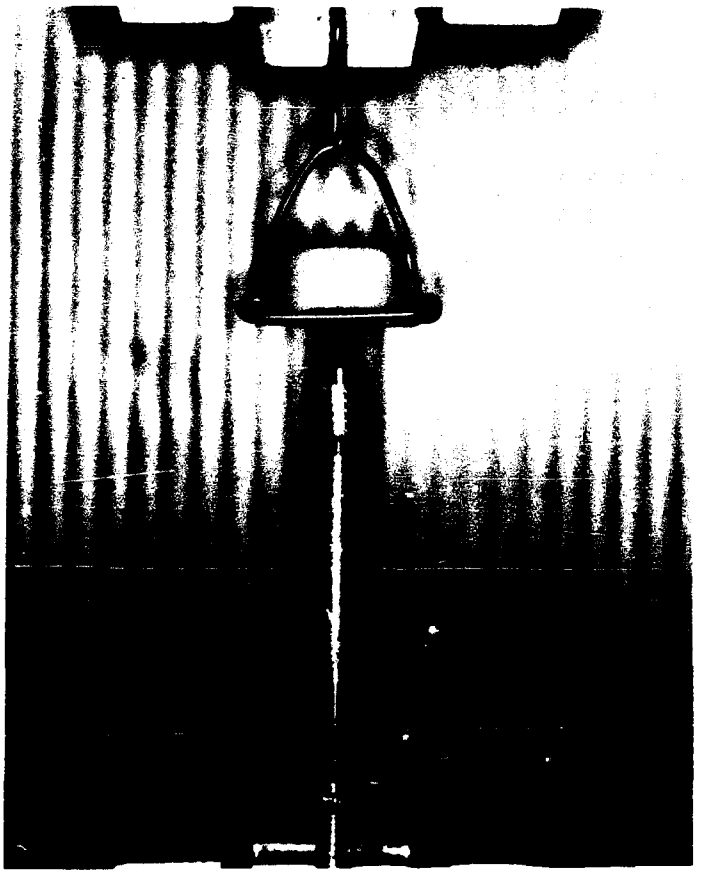


FIGURE 6. A restored specimen covered with tin foil and sealed with nail polish.

FIGURE 7. A *longitudinal* section through the restoration.

FIGURE 8. The microscope and ultraviolet lights used for the evaluation of microleakage specimens.

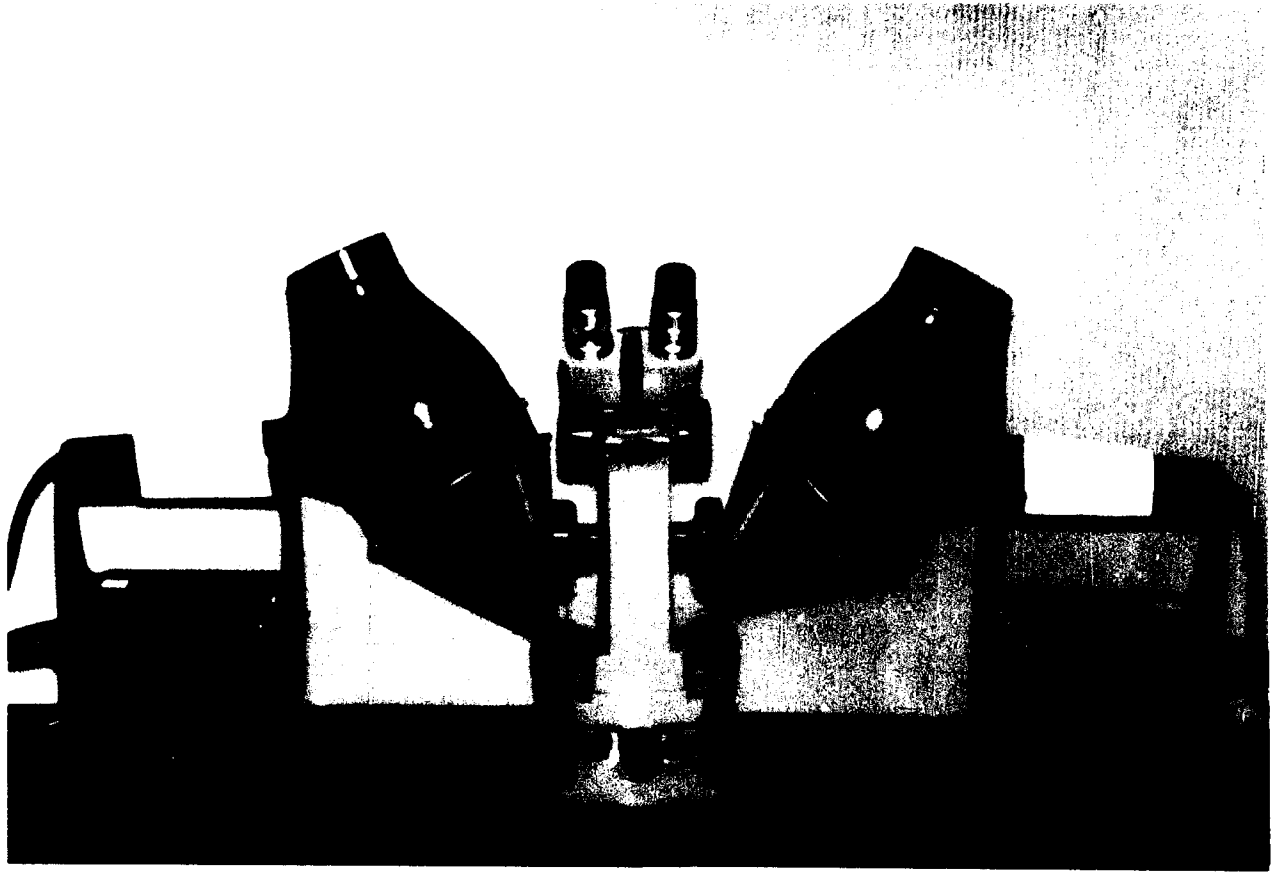


FIGURE 9. The standard used in the evaluation of the microleakage specimens.

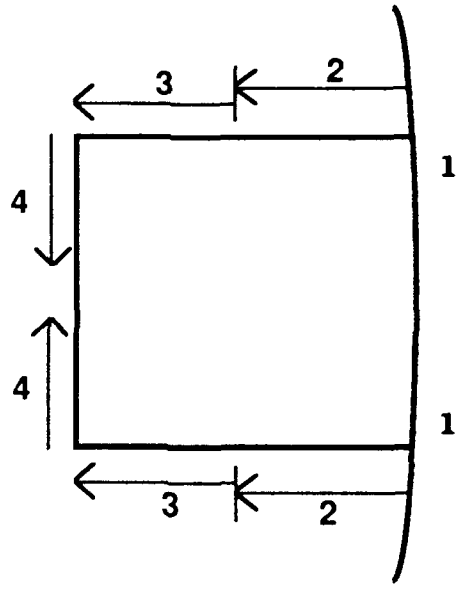

3
2
1
4
4
1
3
2

FIGURE 10. Mean loads at failure of the five treatment groups.

Treatment Groups:

1. No Treatment
2. Copalite
3. Prisma Universal Bond 2
4. Panavia EX
5. Amalgambond

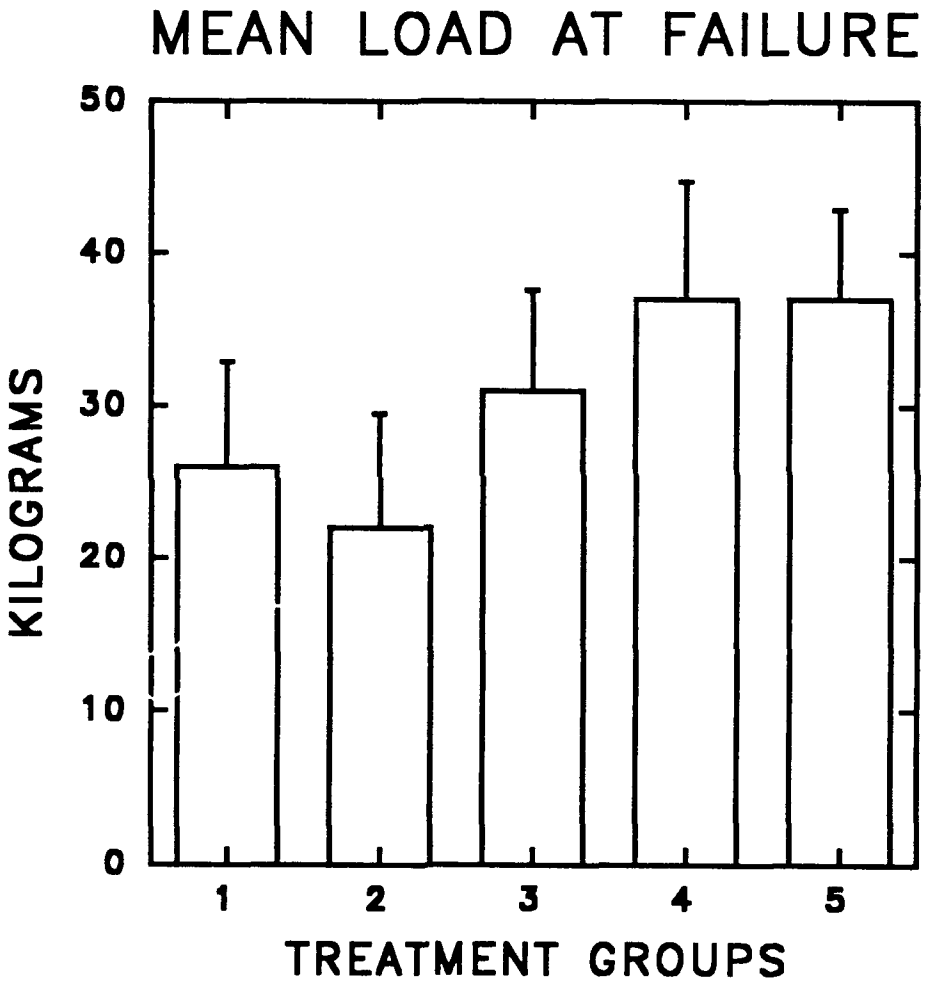
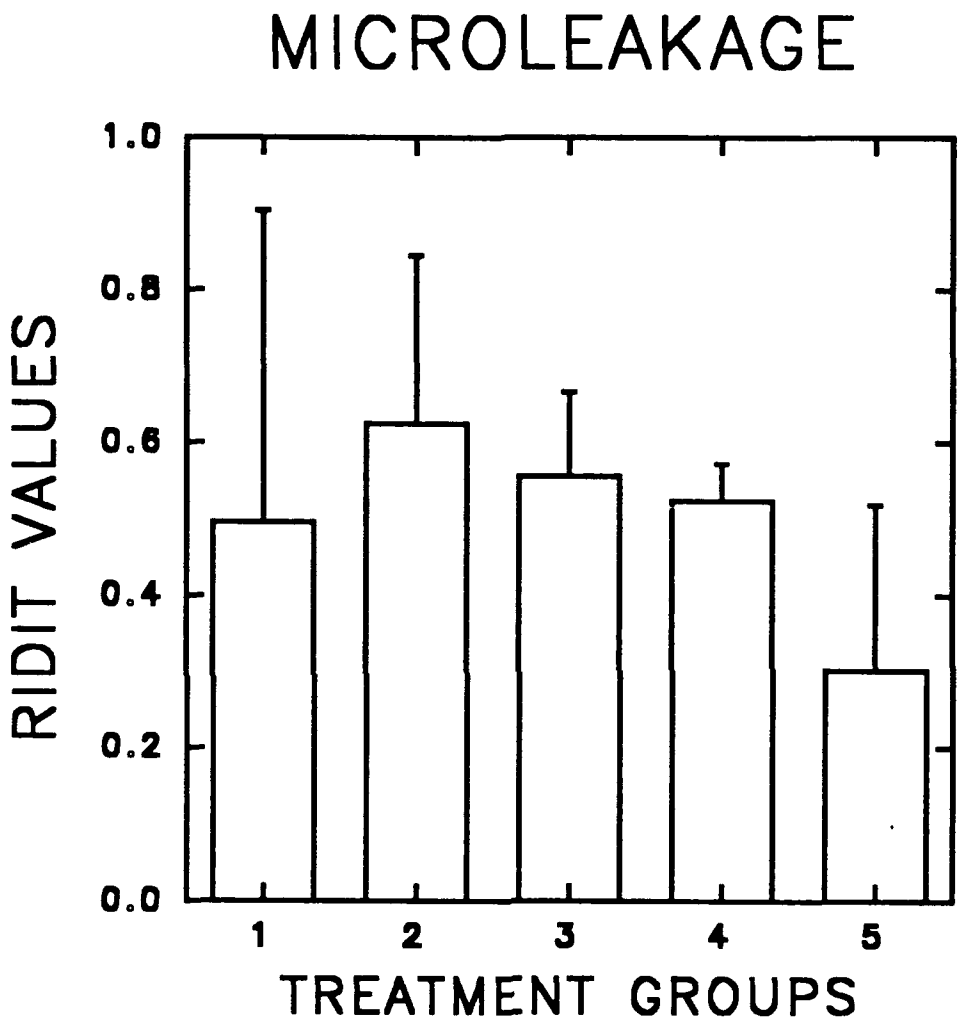

MEAN LOAD AT FAILURE
KILOGRAMS
50
40
30
20
10
0
1
2
3
4
5
TREATMENT GROUPS

FIGURE 11. Microleakage of the five treatment groups.

Treatment Groups:

1. No Treatment
2. Copalite
3. Prisma Universal Bond 2
4. Panavia EX
5. Amalgambond



Ridit Values: Category 1= 0.11
Category 2= 0.52
Category 3= 0.82
Category 4= 0.92

FIGURE 12. An example of a mixed failure between the amalgam and tooth structure which occurred during debonding.

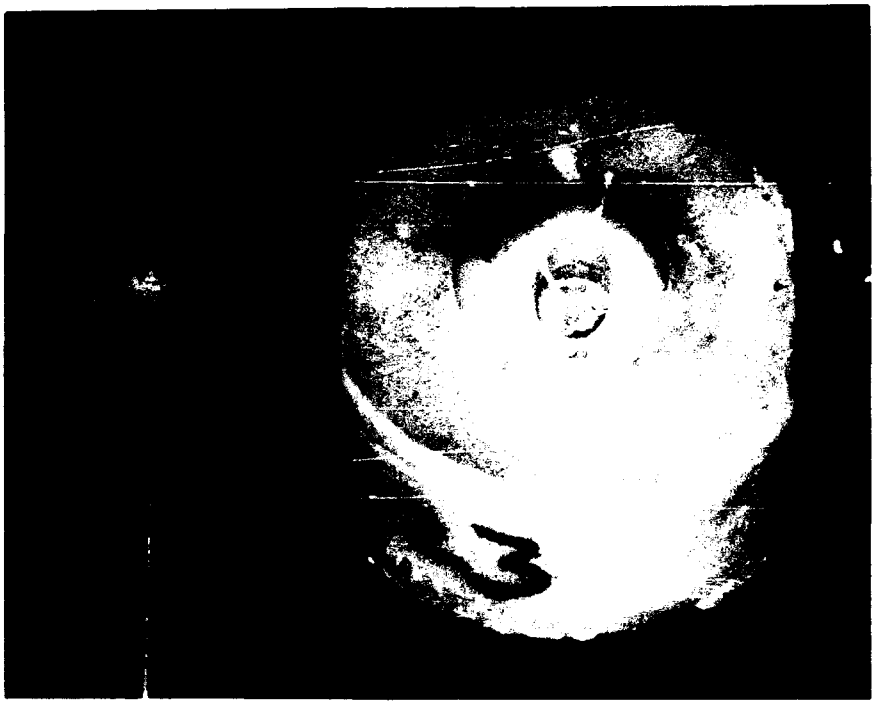


FIGURE 13. An example of an adhesive failure between the amalgam and tooth structure which occurred during debonding.

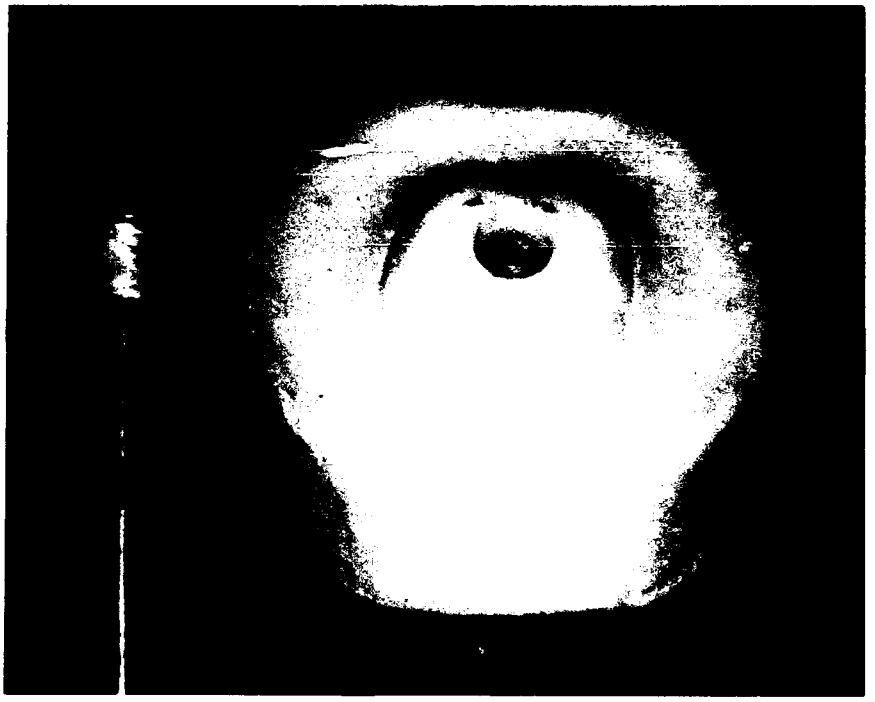


FIGURE 14. An example of a specimen exhibiting Category 1 leakage.

FIGURE 15. An example of a specimen exhibiting Category 2 leakage.

FIGURE 16. An example of a specimen exhibiting Category 3 leakage.

FIGURE 17. An example of a specimen exhibiting Category 4 leakage.

FIGURE 18. An example of a specimen exhibiting axial wall leakage in the absence of occlusal and gingival margin leakage.

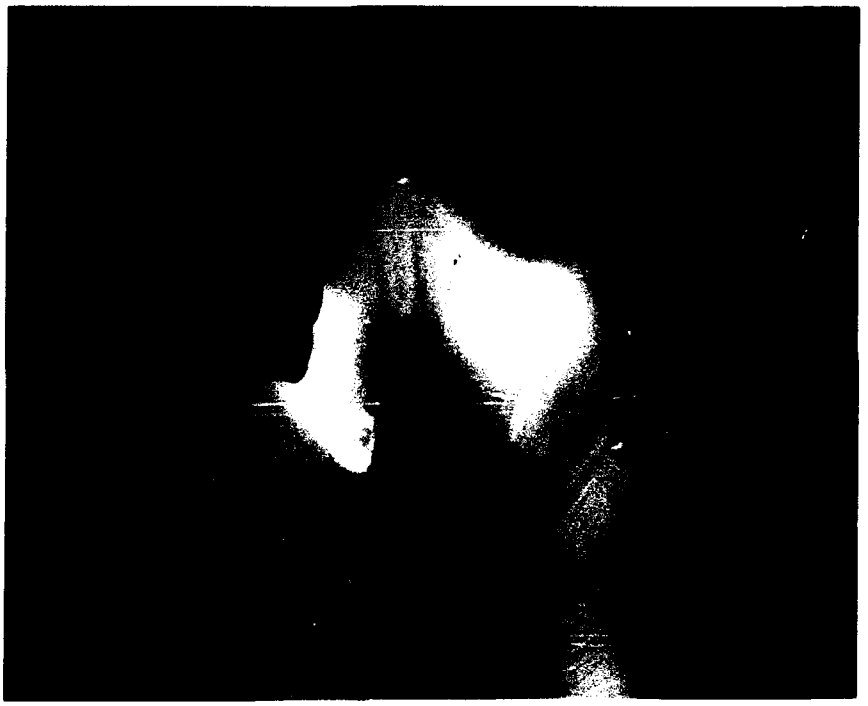


TABLE I

Three adhesive resin systems used

Adhesive Resin Agent	Manufacturer
Prisma Universal Bond 2	Caulk/Dentsply, Milford, DE
Panavia EX	Kuraray, Co., Osaka, Japan
Amalgambond	Parkell Bio-Materials, Farmingdale, NY

TABLE II

Load at failure (kg) of the five treatment groups

Cavity Treatment	Mean (S.D.)	Range
Copalite	22 (7.51)	10 - 35
No varnish or liner	26 (6.86)	18 - 43
Prisma Universal Bond 2	31 (6.57)	17 - 42
Amalgambond	37 (5.88)	27 - 52
Panavia EX	37 (7.69)	26 - 54

N = 20

Vertical lines connect nonsignificant differences at the 0.05 probability level.

TABLE III

Distribution of failure mode of
the five treatment groups

Cavity Treatment		N	Mode of failure A	M	C
1	No varnish or liner	20	20	0	0
2	Copalite	20	17	3	0
3	Prisma Universal Bond 2	20	14	6	0
4	Panavia EX	20	7	13	0
5	Amalgambond	20	14	6	0

N: Total number of specimens
A: Adhesive failure
M: Adhesive and tooth structure cohesive failure
C: Tooth structure cohesive failure

TABLE IV

Distribution of the degree of microleakage
of the five treatment groups

Group	N	Leakage Categories 1	2	3	4
1 No varnish or liner	20				
occlusal		11	0	0	9
gingival		10	0	0	10
2 Copalite	20				
occlusal		0	13	1	6
gingival		2	12	0	6
3 Prisma Universal Bond 2	20				
occlusal		0	19	1	0
gingival		0	16	3	1
4 Panavia EX	20				
occlusal		0	20	0	0
gingival		0	19	1	0
5 Amalgambond	20				
occlusal		11	8	1	0
gingival		11	9	0	0

N -- total number of specimens

TABLE V

Comparison of microleakage of the five treatment groups

Group		Ridit Mean	Standard Deviation
1	No varnish or liner	.50	.41
2	Copalite	.62	.22
3	Prisma Universal Bond 2	.56	.11
4	Panavia EX	.52	.05
5	Amalgambond	.30	.22

Vertical line connects nonsignificant differences at the 0.01 level.

Ridit Values: Category 1 = 0.11
Category 2 = 0.52
Category 3 = 0.82
Category 4 = 0.92

TABLE VI

Rank orders of load at failure and microleakage of the five treatment groups

Group		Load at Failure	Leakage
1	No varnish or liner	3	2
2	Copalite	4	5
3	Prisma Universal Bond 2	2	4
4	Panavia EX	1	3
5	Amalgambond	1	1

1 -- denotes the highest load at failure and the least leakage.
5 -- denotes the lowest load at failure and the most leakage.

DISCUSSION

This in vitro study evaluated the effectiveness of adhesive resins as lining agents between amalgam restorations and tooth structure with respect to their ability to increase retention of the restorations and to reduce marginal leakage. Their ability to provide bonding between the restoration and cavity walls was determined by measuring the load required to remove the restoration from the cavity (load at failure). Their efficacy in reducing microleakage was determined by evaluating the degree of penetration of a fluorescing dye along the gingival and occlusal margins. The results of this investigation are discussed separately for each test.

Load at Failure

The use of adhesive resins as lining agents with amalgam has recently been suggested.[94] One intent of their use is to establish a bond between the amalgam and the enamel/dentin of the tooth structure which will improve retention of the restoration.

Results of the bonding tests are given in Table II and Figure 10. Significantly higher mean loads at failure were observed for the Panavia EX and Amalgambond groups compared to the other three. This is consistent with the findings of other researchers[95,104] who have determined that Panavia and a 4-META-based resin have the ability to bond amalgam to both enamel and dentin. Comparisons between the two systems in their ability to provide adhesion do not, however, yield results

that are as unequivocal. As can be seen in Table II mean failure loads for the two systems were found to be the same. This is at odds with the results of other investigators. Shimizu et al.[105] found that Amalgambond provided a stronger bond between amalgam and enamel than did Panavia. Cooley et al.[107] also noted significant differences between the two systems when bonded to amalgam alloys; however, these researchers determined that Panavia produced a stronger bond than did the 4-META-based adhesive. These differences in bonding ability between systems may well be due to differences in study design. The first group of researchers, for example, was primarily concerned with the evaluation of adhesiveness of these resins to tooth structure when the enamel and dentin were altered by surface treatments with fluoride and intermediate lining materials such as glass ionomer cements. The design of the second study was directed toward measurement of the ability of the resins to adhere to amalgam alloy where the surface had been altered with diamond burs or an air polisher. It is quite likely that these variations in design and intent had a bearing on the results and, at the very least, make direct comparisons between the systems difficult.

Regardless of the differences in results found by other researchers, the fact that the Panavia EX and Amalgambond groups had the same mean loads at failure does warrant discussion. The identical values may be related to the nature of the failures observed. As shown in Table III, the predominant mode of failure for Panavia EX was mixed with failure occurring between the amalgam and the cavity preparation and within the tooth structure itself. An example of this type of failure is shown in Figure 12. The failure mode for specimens lined with Amalgambond was

consistently adhesive between the amalgam and tooth structure (Figure 13). For Amalgambond, few cases of cohesive failure within the tooth structure occurred. It is conceivable, considering the high percentage of mixed failures involving tooth structure which was observed for the Panavia specimens, that these values are artificially low and were influenced by enamel and dentin fracture strength. True failure loads for Panavia EX may actually be higher than those measured.

The mean failure load for the Prisma Universal Bond 2 group was significantly higher than for the Copalite and untreated groups. This result is difficult to compare with the findings of other studies because most investigators who have evaluated the ability of resins to provide bonding between amalgam and tooth structure have limited their evaluations to systems such as Panavia and 4-META resins which claim the ability to bond to metals. The manufacturers of Prisma Universal Bond 2 do not make such a claim.

Although the difference was not significant, the mean load at failure of the untreated group was higher than that of the Copalite treated group. The lower value for the Copalite group may have been due to the ability of the varnish to fill in slight undercuts in the cavity walls produced by the cutting action of the bur. This would have had the effect of reducing retention between the amalgam and tooth structure.

It is believed that the method used in this study to test the ability of these resins to bond amalgam to tooth structure provides a good measure of the actual adhesive capacity of the systems. Several parts of the experimental design were incorporated in an attempt to ensure that the test would be a fair measure of that capacity. Uniformity of the cavity

preparation and standardization in the technique of restoration placement were viewed as critical if the results were to be accepted as a true reflection of the actual situation. Naturally, from specimen to specimen, surface area of the cavity walls needed to be the same. Although this is almost impossible when the human element is involved, uniformity was maintained to a degree that ensured reproducible surface areas from one specimen to another. It was also felt that the application of a varnish coating to the heads of the nails used in the removal of the amalgam restorations from the preparations was important in that it eliminated the potential for the adhesive resin to bond the metal nail head to the dentin of the pulpal floor. If this had occurred, the load at failure would not have been an accurate reflection of the adhesiveness at the interface between the restoration and the tooth structure. Finally, taking precautions during nail placement and specimen loading to ensure that the load applied would be as parallel to the cavity walls as possible helped to prevent the test results from being influenced by forces acting unevenly at the amalgam/tooth structure interface.

Microleakage

In addition to providing a bond between amalgam and tooth structure, the adhesive resins have been proposed as liners in hopes that they would reduce the degree of microleakage that normally occurs at the interface between the restoration and tooth structure.

Results of the microleakage test are provided in Table V and Figure 11. The use of Amalgambond resulted in significantly less leakage than did the other treatments. Although comparison of this result with

previous studies is difficult because of the paucity of published reports concerning the use of 4-META resins to reduce leakage with amalgam, at least one study has reached similar conclusions. Varga et al.[95] found that a 4-META-based adhesive significantly reduced microleakage when used as a liner with amalgam.

The finding that the other adhesive resins, Panavia EX and Prisma Universal Bond 2, did not significantly reduce leakage when compared to the Control group is at odds with the results of several other investigators. Yu et al.[92] and Staninec and Holt[94] found that the use of Panavia as an amalgam liner reduced leakage when compared to an unlined treatment group. Yu et al.,[89] Ben-Amar et al.,[91] and Liberman et al.[108] similarly found that other adhesive resins were efficacious in reducing the degree of leakage around amalgam restorations.

Another finding of this investigation which is contrary to the results of many other similar studies[83-86] is the fact that the Copalite treated group exhibited more leakage than did the untreated group. Although the differences were not statistically significant, the numerical difference in ridit means was clear. As a matter of fact, the Copalite group exhibited more leakage than all of the other treatment groups.

For the most part, the evaluators had little difficulty in assigning specimens to a category indicating their degree of leakage. Well defined patterns of dye fluorescence were exhibited by most specimens (Figures 14-17). A deviant pattern of fluorescence, however, was troublesome. In some instances, fluorescence was clearly visible along the axial wall of the restoration although no sign of dye penetration was visible along either the occlusal or gingival walls (Figure 18). One explanation is that

leakage occurred from the pulp chamber to the axial wall. If this were true, it would obviate the need for occlusal or gingival margin leakage as a means of accounting for the axial leakage. This explanation is without merit, however, because careful examination of the pulp chambers of the involved specimens yielded no sign whatever of dye presence. A second expianation for this pattern is that while leakage did not occur at the occlusal or gingival margins, it did occur elsewhere along the amalgam/tooth interface out of the plane of the sectioning sawblade. This theory, while plausible, must be considered suspect for several reasons. The first is that this pattern of leakage is rarely, if ever, encountered in the plethora of leakage investigations done over the last 30 years. The pattern is conspicuous in the literature by its absence. If it had been routinely encountered in past studies, a multiple sectioning technique of specimen preparation would have developed as a requirement for accurate leakage assessment. This has clearly not been the case. Another reason for discounting this explanation is that multiple sections of individual specimens have been evaluated for leakage and no patterns of nonuniform leakage have been seen.[109] Although this work was limited, it does indicate that leakage tends to be uniform at a restoration's margins. Another explanation for this axial pattern is that leakage at the occlusal or gingival margins has actually taken place and that the dye has penetrated along one or both of the margins to the depth of the axial wall, but that it is not present in sufficient amounts to cause fluorescence. If true, this would bode poorly for the future of the fluorescent dye technique as a means for microleakage assessment. Clearly, if dye can

penetrate along a margin and not be detected, it would be quite useless as a method for evaluating leakage.

These rather significant questions concerning the ability of fluorescent dye to detect small amounts of leakage, coupled with the results indicating that Copalite was ineffective in reducing leakage when compared to the untreated Control group, bring into question the efficacy of this marker as an indicator of leakage. Adding to these concerns are the rather large standard deviations seen with some of the treatment groups. The untreated group in particular had a large standard deviation which reflected the fact that 21 of its leakage scores were in Category 1 and the remaining 19 were in Category 4.

These results strongly suggest that additional research needs to be done to address these concerns. Future work may be directed toward determining if leakage is uniform or nonuniform at all points along a restoration's margins. Additionally, the validity of using fluorescent dyes as a leakage marker should be confirmed or denied by comparing it with other well-tested techniques such as Ca^{45} autoradiography.

Relationship Between Bond and Microleakage Tests

It is apparent from an examination of the results of these two tests that a precise correlation does not exist between them. Some measure of correlation is present, however, and becomes evident when the results of the bond and microleakage tests are compared (Table VI). The Amalgambond group exhibited the least leakage and had the highest mean load at failure. It exhibited significantly less leakage than the other four treatment groups and had a load at failure which was significantly greater

than all other groups with the exception of the Panavia EX group. The Copalite group had the most leakage and the lowest mean load at failure. Although its leakage mean was significantly greater than only one other group, its mean load at failure was significantly lower than three of the five other groups.

These results indicate that only imprecise correlation exists between these two tests and that neither one should be used as an absolute predictor of the other.

SUMMARY AND CONCLUSIONS

This in vitro study evaluated the ability of three commercially available adhesive resins to reduce microleakage and provide retention between amalgam restorations and tooth structure. Microleakage evaluation was performed by measuring the degree of penetration of an ultraviolet fluorescing dye at both the occlusal and gingival margins of class V amalgam restorations placed in extracted human teeth. Retention was determined by measuring the mean load at failure of class V amalgam restorations placed in extracted human teeth. Both groups of specimens were stored in distilled water at 37°C. Prior to testing, the specimens were subjected to 2,500 thermal cycles at a temperature differential of 40°C. The tests were performed five days after specimen preparation.

The findings of this study are as follows:

1. The Amalgambond group exhibited significantly less leakage than did the other four treatment groups. The Control group ranked second, while the Copalite group exhibited the most leakage. No significant differences were found between the Control, Panavia EX, Prisma Universal Bond 2, and Copalite groups.
2. Restorations placed in preparations lined with Amalgambond or Panavia EX exhibited significantly greater retention than did restorations placed in unlined cavities or in those lined with Prisma Universal Bond 2 or Copalite. Amalgam restorations placed in preparations lined with Prisma Universal Bond 2

exhibited significantly greater retention than did restorations placed in unlined or Copalite-lined cavities.

3. Lack of a precise correlation between degree of microleakage and mean load at failure suggests that neither test should be used as an absolute indicator of the other.

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CURRICULUM VITAE

ABSTRACT

AN IN VITRO EVALUATION OF THE USE OF ADHESIVE RESIN LINERS TO REDUCE MICROLEAKAGE AND IMPROVE BOND STRENGTH OF AMALGAM RESTORATIONS

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This in vitro study evaluated the ability of three commercially available adhesive resins to reduce microleakage and provide retention between amalgam restorations and tooth structure. Microleakage evaluation was performed by measuring the degree of penetration of an ultraviolet fluorescing dye at both the occlusal and gingival margins of class V amalgam restorations placed in extracted human teeth. Retention was determined by measuring the mean load at failure of class V amalgam restorations placed in extracted human teeth. Both groups of specimens were stored in distilled water at 37°C. Prior to testing, the specimens were subjected to 2,500 thermal cycles at a temperature differential of 40°C. The tests were performed five days after specimen preparation.

The Amalgambond group exhibited significantly less leakage than did the other four treatment groups. The Control group ranked second, while the Copalite group exhibited the most leakage. No significant differences

were found between the Control, Copalite, Prisma Universal Bond 2, and Panavia EX groups.

Mean loads at failure were greatest for the Panavia EX and Amalgambond groups and were significantly higher than those of the other three groups. The Prisma Universal Bond 2 group had the third highest mean failure load. The Control group and Copalite group had mean failure loads significantly lower than that of the Prisma Universal Bond 2 group.

No precise correlation between degree of microleakage and load at failure was found to exist although the groups exhibiting the highest and lowest values for both tests did show some measure of correlation. The Amalgambond group, which exhibited the least leakage, had the highest mean load at failure while the Copalite group exhibited the most leakage and had the lowest mean failure load.